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Analysis about Delay of Container Trunk Lines and Offshore Waiting for Calling to Congested Container Terminals

Abstract

Delays of container services have increased since the formation of three major shipping alliances accompanying the upscaling of container ship size. These delays have had a serious impact on sophisticated global supply chains such as just-in-time systems. This study quantifies the delay on container trunk lines, analyzes the causes, and estimates the offshore waiting time of calling ships at congested terminals.

Delays of container ships deployed on trunk lines were calculated by comparing the actual arrival/departure times in ship movement data and the scheduled times at calling ports. The offshore waiting time of ships for calling at container terminals was estimated by calculating the total time and the hourly ship speed between entering port and the berthing terminal, and detecting anchoring signals utilizing AIS data.

The results revealed that approximately 80 % of delays on trunk lines in 2018 occurred at ports in China, Europe, and North America. In these ports, the offshore waiting time-volume index proposed in this paper was related to the berth occupancy ratio, defined as the ratio of occupied time and space by ship berthing, the total TEU capacity of berthing ships, and the actual delays of arrivals and overtime stays.

Keywords: *container service, delay, punctuality rate, offshore waiting, berth occupancy.*

1. Introduction

The extent of delays in container services has increased considerably in recent years. Figure 1 shows the punctuality rate, defined as the rate of arriving within 24 hours of the scheduled time at each port, of world container services. Punctuality rates decreased continuously from 2016 to 2018, recovered in 2019, and then decreased again in 2020. In November and December of 2020, the rate fell to below 50 %. Although various factors are assumed as causes of the low punctuality rate, one of the largest is congestion at ports and terminals. On the East-West container trunk line between Europe/North America and East Asia, the integration of alliances and their services has progressed accompanying the upscaling of container ship size, and as a result, services tend to concentrate on calls at specific ports and terminals. For example, among 18 services on the North Europe and East Asia route by three major alliances, 17 services called at the Port of Rotterdam and 14 services called at the Port of Shanghai in 2019.

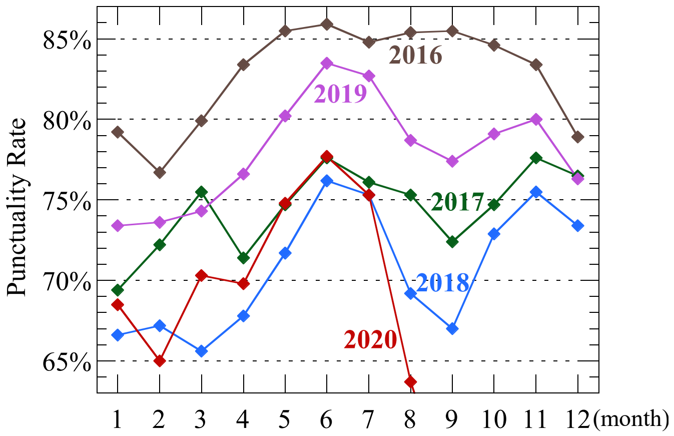

Figure 1 – Punctuality rate of world container services

Source: Sea-Intelligence (2020) & Alan Murphy (2017)

The deterioration in punctuality of maritime container services has a great impact on global supply chains. Lean and sophisticated supply chains, exemplified by the just-in-time system, also have the aspect of fragility against transport disruptions. For example, car production by Japanese auto makers in the U.S. stagnated during the 2014-2015 U.S. West Coast port disruption. Although auto makers attempted to divert transportation of auto parts to air cargo transport, it was difficult to maintain a sufficient supply of parts. Similarly, Japanese auto factories in Europe were forced to interrupt production due to an insufficient transport capacity of container service in December of 2020. As an example, because one Japanese auto maker stocks parts only for around 5 to 7 days at factories in Europe and North America, alternative air transportation from Japan is needed when maritime container services are delayed for more than several days.

Considering above mentioned background, in this study, first, the delays of container ships deployed in the services of three major shipping alliances on East-West trunk lines were calculated by comparing the actual arrival/departure times in the ship movement data and the scheduled times at calling ports. Based on the results, the offshore waiting times of ships calling at container terminals were estimated by calculating the total time and hourly ship speed between entering port and the berthing terminal and detecting anchoring signals utilizing AIS (Automatic Identification System) data.

2. Literature Review

At one time, shipping companies published the punctuality rates of their services on web pages such as "On-Time Performance" of the Mitsui OSK Line, however, that kind of information cannot be found recently. Sea-Intelligence collects the punctuality rates of world container services, as shown in Figure 1, but does not release detailed data by ship and port or reports analyzing delay factors. In the academic field, Notteboom (2006) discussed the management of the time factor in liner services and introduced the results of a survey concerning the sources of schedule unreliability on the East Asia–Europe route. Pani *et al* (2013) constructed a model for prediction of delayed arrival at container terminals by utilizing machine learning in order to allocate resources more efficiently. Salleh *et al* (2017a, 2017b) developed a prediction model for container ship arrival and departure punctuality under different environments and indicated that arrival punctuality depended on many factors, such as the punctuality of departure from the previous port, the vessel and current port condition, and the reliability of agents. Hasheminia and Jiang (2017) analyzed the delay of container ships and scheduled operations during a 9-month period at seven terminals of three North American ports and pointed out the possibility that shipping lines strategically balanced the trade-off between delay costs and schedule recovery costs. Grida and Lee (2018) estimated the berthing and sailing times of mega container ships from a dataset of vessel sizes, distances between ports, port demand, and other factors. Yu *et al* (2018) attempted to predict the delay or advance of ships at Gangi Terminal in the Port of Ningbo-Zhoushan in China and discussed the value of the prediction method for daily container terminal operation. These previous studies, however, did not have any direct relationship with the large decrease in container service punctuality in recent years shown in Figure 1.

As to offshore waiting due to terminal congestion, Gao *et al* (2016) traced container ship navigation in Japan's Seto Inland Sea and its oceanic waters by AIS data and identified offshore anchoring ships whose speeds over ground (SOG) were below 3 knots and positions were not near any berths at ports. Marine Traffic provides the numbers and times of anchoring ships at designated offshore waiting sea areas for the index of port congestion. However, in both cases, the research and data did not analyze the relationship between the berthing terminal and the offshore waiting ship. From another point of view, many previous studies have examined the optimization of berth allocation, including Lai and Shih (1992), Imai *et al* (2001), Dai *et al* (2008), Buhrkal *et al* (2011), and Bierwirth and Meisel (2015). Although vessel waiting time is one important criterion for optimization, the objective of those studies was to improve the terminal operating efficiency of a specific or virtual terminal by simulating the effect of allocation policies and procedures, and estimation of the actual offshore waiting times for various terminals was outside the scope of research.

The contribution of the present study to the literature is two-fold: First, the delay of East-West container services was quantified in broad terms, and the causes of delays were analyzed. Second, an estimation method for the offshore waiting times of ships at each container terminal was constructed, making it possible to discuss the relationship between waiting time and the situation and characteristics of terminals such as the degree of congestion and delay of ship arrival.

The remainder of this paper is structured as follows. In section 3, the delays of major services on East-West trunk lines at each port are calculated and the causes of those delays are analyzed. Section 4 describes estimation methods for offshore waiting times and analyzes the results associated with various factors. Section 5 discusses a method for decreasing delays of container services and waiting times of ships at terminals, and section 6 summarizes the conclusions.

3. Delay of Trunk Line Services

3.1 Calculation Method and Data

Delays of ships deployed in major services on East-West trunk lines were calculated by comparing the actual arrival/departure times and scheduled times at calling ports. The actual times were determined from the ship movement data supplied by Lloyd's List Intelligence (LLI). Table 1 shows the data structure of the LLI data, including the actual arrival and sailing dates and times. These dates and times were arranged by utilizing AIS data received at each port. Figure 2 shows the comparison between the AIS data and the ship movement data. From this comparison, the arrival time in the ship movement data indicates the time when a ship arrived in front of the calling berth and slowed to almost a stop.

Comparison with the actual ship schedule was sometimes difficult when using the LLI ship movement data. First, ships sometimes changed their order of calling at ports for some reason, such as port congestion. In this case, the data were not used to calculate delays. Second, the arrival and departure times at ports where AIS data were not received were automatically input as 11:00 and 13:00, respectively. Among major container ports, AIS data were not available for the Ports of New York and Wilmington. Therefore, the data for those ports were excluded from the analysis. Because both ports received AIS data in the 2017 movement data, the authors asked LLI the reason for the missing data, but did not receive an answer.

Table 1 – Data structure of LLI ship movement data

IMO No.	VESSEL NAME	TEU Capa.	PLACE NAME	CNTRY	ARRIVAL DATE/YIME		SAIL DATE/TIME	
982****	**********	12,400	Singapore	SGP	2018/9/2	0:43	2018/9/3	2:52
982****	**********	12,400	Cai Mep	VNM	2018/9/4	23:45	2018/9/5	15:33
982****	**********	12,400	Yantian	CHN	2018/9/8	9:47	2018/9/9	12:58
982****	**********	12,400	Ningbo	CHN	2018/9/11	23:14	2018/9/12	18:14
982****	**********	12,400	Yangshan	CHN	2018/9/16	4:51	2018/9/17	6:12
982****	**********	12,400	Long Beach	USA	2018/9/28	4:11	2018/10/3	7:03
982****	**********	12,400	Oakland	USA	2018/10/4	16:13	2018/10/6	5:40
982****	**********	12,400	Busan	KOR	2018/10/19	3:19	2018/10/20	8:34
982****	**********	12,400	Yangshan	CHN	2018/10/21	14:26	2018/10/22	16:05
982****	**********	12,400	Ningbo	CHN	2018/10/24	16:34	2018/10/25	14:51
982****	**********	12,400	Hong Kong	CHN	2018/10/27	10:33	2018/10/28	2:45
982****	**********	12,400	Singapore	SGP	2018/10/31	12:51	2018/11/1	10:45

Source: LLI

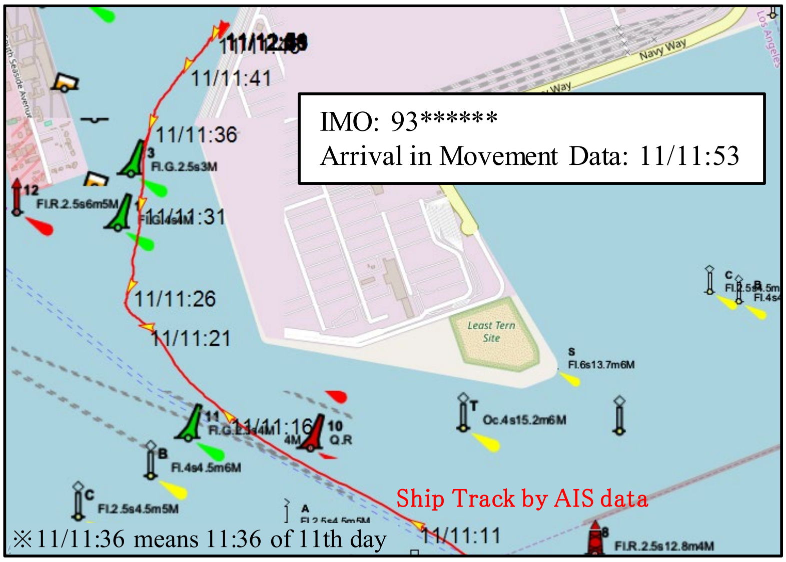

Figure 2 – Comparison of AIS data and ship movement data at Port of Los Angeles

Source: AIS and Ship Movement Data of LLI

The target services of the analysis were 58 services on East-West trunk lines by three alliances, 2M, The Alliance and Ocean Alliance, as shown in Table 2, from April to December 2018. The calling ports of the North Europe services included ports on the North Atlantic Ocean, the North Sea, etc., and some services also included ports on the Mediterranean Sea. Similarly, the calling ports of the East Coast of North America services included ports on the Atlantic side of the continent and some services through the Panama Canal also including ports on the Pacific side. The scheduled dates/times of the services were obtained from the websites of shipping companies. Ships which were deployed for each service were identified by the MDS Containership Databank and Ocean Commerce International Transportation Handbook 2019. However, it was not possible to identify some ships because many ships changed their services in the middle of the year.

Table 2 – Target services of analysis

Alliance (Shipping Company)	Europe - East Asia		North America - East Asia	
	North Europe	Mediterranean	West Coast	East Coast
2M (Maersk/MSC)	AE1, AE2, AE5, AE6, AE7, AE10	AE11, AE12, AE15, AE20	TP2, TP6, TP8, TP9	TP10, TP11, TP12, TP16, TP17, TP18
The Alliance (Hapag/ONE/Yang Ming)	FE1, FE2, FE3, FE4, FE5	MD1, MD2, MD3	PN1, PN2, PN3, PS3, PS6	EC1, EC2, EC4, EC5
Ocean Alliance (APL/COSCO/OOCL /Evergreen/CMA CGM)	AEU1, AEU2, AEU3, AEU5, AEU6, AEU7	AEM1, AEM2, AEM3, AEM6	CEN, CPNW, EPNW, MPNW, OPNW	AWE1, AWE2, AWE3, AWE4, AWE5, GME2

※Service names are by underlined shipping company

Delays of container services were investigated from the following two viewpoints:

- ✓ Delays at ports of import: Delays at ports of import were calculated as the difference between the actual and scheduled arrival date/time. Ports of import were identified by the calling order of the ports in each service. The punctuality rates, defined as the rate of arriving within 24 hours of the scheduled time, were also calculated.

- ✓ Occurred delays at each port: Delays which occurred at port *i*: ΔD_i were calculated by equations (1) and (2).

$$D_i = ATS_i - STS_i \tag{1}$$

$$\Delta D_i = D_i - D_{i-1} \tag{2}$$

where D_i is the difference between the actual time of sailing ATS_i and the scheduled time of sailing STS_i at port *i*. In case ΔD_i was less than 0, it was juged that a delay did not occur.

3.2 Calculation Results

The calculation results of the delays at the ports of import are shown in Table 3. The total average arrival delays of the Europe-East Asia route were less than 1.0 day in both areas. The average delays at East Asian ports were on the same level, while at European ports, the average delay of 2M for the North Europe route and The Alliance for the Mediterranean route exceeded 1.0 day. Maximum delays, defined as the average of the maximum delays of the component services, were in the range of about three to five days. Although the punctuality rates were in the range of approximately 60 % to 75 %, the rates of 2M for the North Europe route and The Alliance for the Mediterranean route were about 50 %. On the North America-East Asia route, the average delays at North American ports were longer than those at East Asian ports. Among North American ports, the average delays of Ocean Alliance for the West Coast route and The Alliance for the East Coast route reached nearly 2.0 days. The maximum delays for North American ports were longer than those for East Asian ports for all alliances on both routes. The punctuality rates for East Asian ports were larger than 60 % excluding The Alliance for the

West Coast route, while the total average for North American ports was about 50 %. The rates of the Ocean Alliance for the West Coat route and The Alliance for the East Coast route were less than 40 %.

Table 3 – Delays in ports of import

Route/Service		Average Delay (day)		Max Delay (day)		Punctuality Rate	
		East Asia	Europe	East Asia	Europe	East Asia	Europe
Europe /E Asia	Total Average	0.81	0.98	3.17	3.71	69.5%	66.4%
	North Europe	0.74	0.87	2.98	3.67	72.5%	67.4%
	2M	0.72	1.16	1.94	3.89	67.9%	52.1%
	The Alliance	0.74	0.81	3.58	3.87	74.9%	72.9%
	Ocean Alliance	0.75	0.64	3.53	3.29	75.2%	78.0%
	Mediterranean	0.92	1.15	3.46	3.76	64.9%	64.9%
	2M	0.88	0.86	2.45	3.15	61.3%	66.9%
	The Alliance	0.88	1.94	4.36	4.77	71.7%	49.3%
	Ocean Alliance	0.99	0.85	3.79	3.63	63.5%	74.7%
Route/Service		East Asia	N America	East Asia	N America	East Asia	N America
N America /E Asia	Total Average	0.91	1.43	3.06	4.47	67.4%	53.5%
	West Coast	1.01	1.54	3.18	4.70	60.6%	51.2%
	2M	0.78	1.00	2.25	3.95	70.0%	66.7%
	The Alliance	1.20	1.59	3.50	4.95	52.8%	55.5%
	Ocean Alliance	1.01	1.92	3.60	5.04	60.9%	34.5%
	East Coast	0.81	1.34	2.96	4.27	73.3%	55.5%
	2M	0.53	0.95	1.43	3.25	85.6%	65.4%
	The Alliance	1.03	1.81	2.97	4.91	60.2%	38.1%
	Ocean Alliance	0.94	1.41	4.47	4.87	69.9%	57.1%

The calculation results of occurred delays at each port arranged by areas by routes are shown in Figure 3. The total values of the routes did not correspond to the figures in Table 3 because shortening the delays at ports compared with their previous ports were regarded as 0 delay, as noted in the explanation of equation (2). Delays in China, Europe, and North America occupied large parts of the total delay, accounting for approximately 80 % of delays on all routes.

The occurred delays of major ports are listed in Table 4. On the Europe-East Asia route, on average, delays of more than a half-day occurred at the Ports of Ningbo and Shanghai, where around 90 % of the services called, while the delay at the Port of Singapore was only around 4 hours. Among European ports, the longest delay was at the Port of Rotterdam, followed by the Port of Hamburg. Similarly, the delays that occurred at the Ports of Shanghai and Ningbo exceeded 0.6 days for the North America-East Asia route. Among North American ports, the longest delay was at the Port of Vancouver, followed by the Port of Savannah.

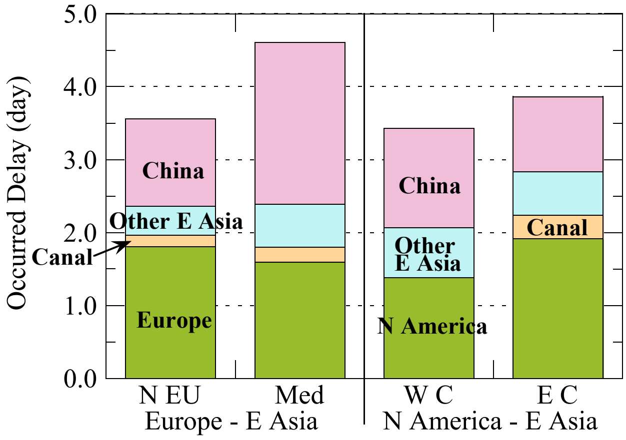

Figure 3 – Occurred delay at ports by routes

Table 4 – Occurred delay in each port

Europe - East Asia				North America - East Asia			
Area	Port	No. of Service	Average Delay (day)	Area	Port	No. of Service	Average Delay (day)
China	Ningbo	25	0.51	China	Shanghai	21	0.67
	Shanghai	24	0.62		Ningo	16	0.67
	Yantian	17	0.20		Yantian	16	0.24
	Qingdao	10	0.57		Qingdao	9	0.32
Korea	Busan	13	0.28	Korea	Busan	17	0.31
SE Asia	Singapore	23	0.18	SE Asia	Singapore	12	0.26
North Europe	Rotterdam	15	0.45	West Coast	Vancouver	8	1.05
	Hamburg	11	0.33		Los Angeles	6	0.44
	Antwerp	9	0.22		Oakland	6	0.38
Mediter -ranean	Piraeus	6	0.31	East Coast	Savannah	13 (10)	0.63
	Valencia	5	0.22		Charleston	9 (8)	0.27
	Malta	5	0.32		Norfolk	9 (6)	0.52

※As to the average delays of North America-East Asia route, the calling just after the Ports of New York and York and Wilmington were excluded. The figures in parentheses are the number of assessed services.

3.3 Analysis of Causes

Delays occur due to differences between the actual time and scheduled time of navigation, port entry including offshore waiting, container handling, and so on. Thus, the actual time can be lengthened for various reasons. Figure 4 shows the causes of delays according to the results of a survey by Notteboom (2006). Although this survey was conducted about 15 years ago and the situation may have changed since then, the greater parts of delays were caused by port/terminal congestion or low productivity.

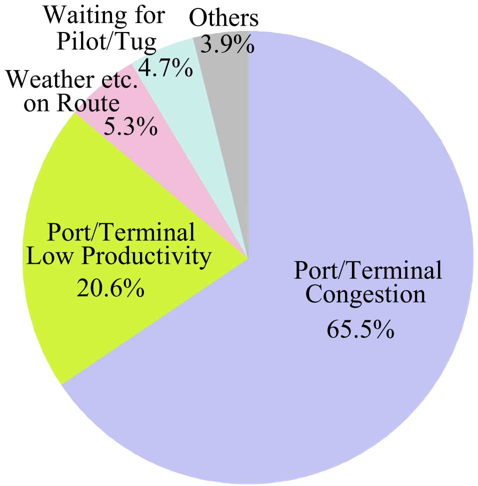

Figure 4 – Causes of schedule unreliability on Europe-East Asia route (2004)
Source: Notteboom (2006)

Because one of the most significant changes in the maritime container market during two decades has been the upscaling of ship size, the relationship between ship size and delays at ports of import by service was investigated, as shown in Figure 5. If container handling time is inadequate for mega container ships, delays should increase as ships become larger. However, a positive correlation between container ship size and delays cannot be seen in Figure 5, indicating that the delays seen in recent years must be caused by other factors.

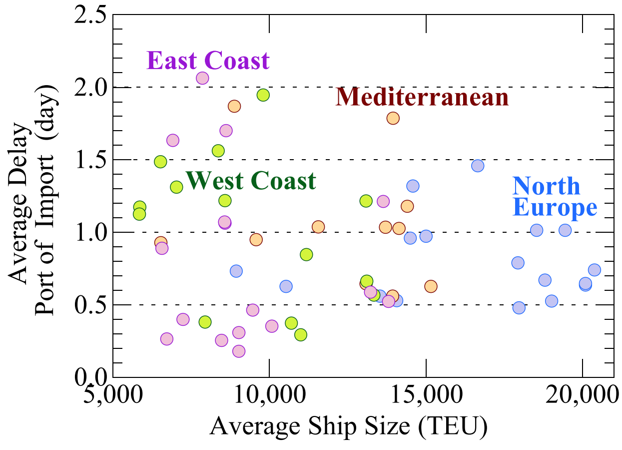

Figure 5 – Relationship between ship size and delays at ports of import

Accompanying the trend toward larger ships, the number of alliances and services has decreased continuously, and as a result, service calls have tended to concentrate on specific ports and terminals. From Table 4, ports with many service calls were inclined to have longer delays, except for the Port of Singapore. The relationship between average delays of ports in Table 4 and average delays of terminals at those ports is shown in Figure 6, except for ports with a single terminal operator. Overall, average terminal delays have some relationship with average port delays, but average terminal delay also differ widely, from about double to half of the average port delay. In any case, however, it can be assumed that congested terminals with many delayed services tend to induce longer delays.

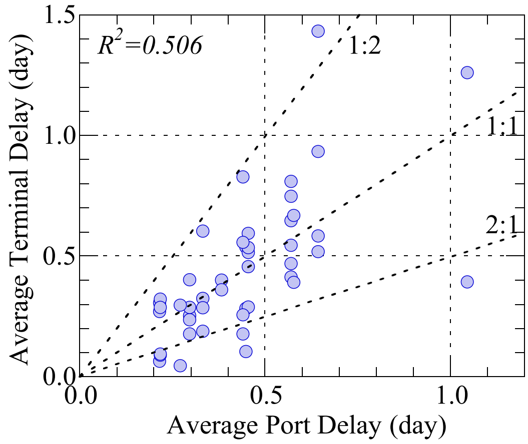

Figure 6 – Relationship between port delay and terminal delay

4. Offshore Waiting at Terminals

4.1. Estimation Method and Data

The previous section revealed that 80 % of delays on East-West trunk lines occurred at ports in China, Europe, and North America, and it is possible that congestion of terminals where calls by many services are concentrated causes a large part of those delays. Based on this result, the offshore waiting times were estimated by terminal at major ports, and the relationship between the waiting time-volume index and various factors of terminals are analyzed in this section.

As to the offshore waiting, generally, each port designates an anchoring area in its port area, but the number of ships that can anchor there is restricted. Therefore, many ships wait outside the port area, and some wait by slowing down or drifting. Figure 7 shows examples of the tracks of offshore waiting ships. The left side of the figure shows the track of an anchoring ship, and the right shows that of a drifting ship. This situation is the reason why it is difficult to grasp all offshore ships simply by observing the anchoring area of each port. Therefore, in this study, offshore waiting ships were identified by the following criteria:

(1) Ships that had the record of "At Anchor" in the navigational status of the AIS signal
(2) Ships that continued a ship speed over ground (SOG) in the AIS signal of less than 3.0 knots over 2 hours
(3) Ships whose total time from port entry to berthing was equal to or greater than the times of ships in (1) and (2)

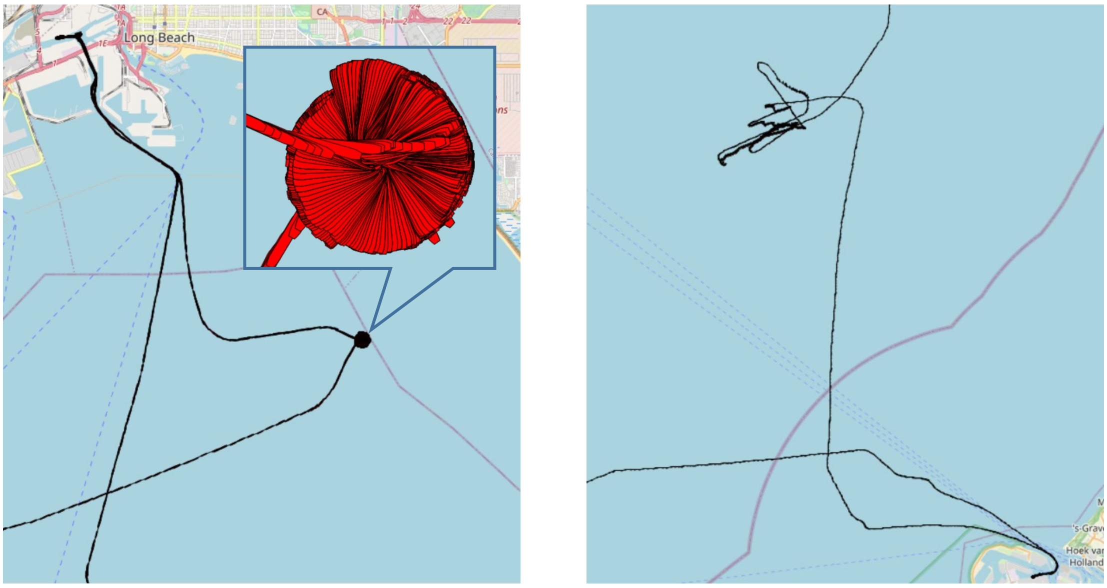

Figure 7 – Examples of tracks of offshore waiting ships (Left: anchoring, right: drifting)

Here, criterion (1) and (2) indicate anchoring ships, which have a track similar to the example shown on the left in Figure 7. Since the navigational status of AIS is switched by the operator, and it is sometimes forgotten, criterion (2) was set based on the reference Gao *et al* (2016). Criterion (3) captures ships that drift and slow down. The total times from port entry to berthing of ships were calculated by setting the areas for identifying port entry and berthing for each port as indicated in Figure 8. The port entry areas were set broadly enough to cover the waiting, anchoring, and drifting locations, and were shaped in a circle to ensure that all ship navigation times are on the same level from all directions. The results of the total time calculation of all berthed ships were placed in ascending order by terminal as shown in Table 5, and, in this case, the offshore waiting ships are identified as ships from No. 7 to 12. Ships No. 7, 11, and 12 had the record of an “At Anchor” signal corresponding to criterion (1), ship No. 9 navigated at a speed below 3.0 knots for 3 hours, corresponding to criterion (2), and ships No. 8 and 10 met criterion (3). Berthing at each terminal was judged when the ship speed was kept below 1.0 knot over 10 minutes at the front sea area of the terminal. The waiting times of ships that moved between terminals were also estimated in the same manner.

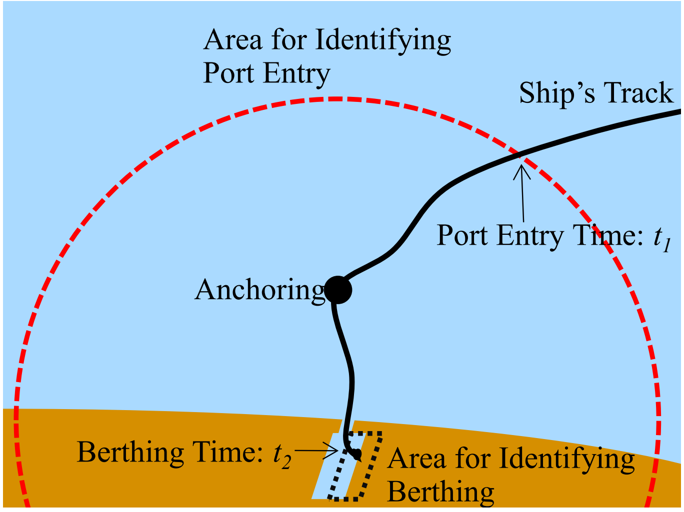

Figure 8 – Image of calculation of total time from port entry to berthing

Table 5 – Image of estimation of offshore waiting times of ships

Total Time	Ship											
t_2-t_1	1	2	3	4	5	6	7	8	9	10	11	12
1	13.8	13.7	17.4	12.6	11.0	15.5	9.0	10.4	9.8	8.2	10.6	10.3
2	12.7	12.9	11.7	10.6	9.9	6.5	0.6	4.2	2.4	8.7	0.8	8.4
3			1.5	2.0	2.7	3.1	3.1	3.8	0.7	3.9	0.7	0.0
4							10.7	5.0	1.3	4.1	0.7	0.0
5							3.3	2.1	4.8	3.5	0.7	0.0
6									1.1	5.4	0.9	0.2
7										0.6	0.9	0.1
8											0.8	0.0
9											5.8	0.0
10											9.7	0.0
11											7.3	0.0
12											4.2	0.0
13												2.8
14												10.0
15												1.2

Offshore Waiting Time

Legends
- Normal Navigation
- At Anchor Signal
- Speeds < 3.0kt
- Anchor Signal & Speeds < 3.0kt

※Numbers in cells mean average ship speeds

The data used in estimating the offshore waiting times were the AIS data by CLS (Collecte Localisation Satellites) and LLI. There are two types of AIS data, which are received by surface antenna and by satellite antenna, respectively. Although the data received by a surface antenna are stable and have a high density compared with the data received by a satellite antenna, the range of that data is limited to the coastwise area. Therefore, the data received by satellite antennas were also utilized to monitor ships movements in offshore sea areas. In addition, the AIS data by CLS and LLI were also integrated to increase the data density. During AIS data processing, irregular navigational tracks with speed of over 30 knots were eliminated.

The analysis targets were the main terminals at top-tier ports in North America, Europe, and China shown below, and the analysis period was one month (October 2019).

Port of Los Angeles (LAX): APMT, China Shipping, Eagle Marine, Ever Green, TraPac, Yang Ming, and Yusen

Port Long Beach (LGB): SSA Pier A, SSA Pier C, LBCT, ITS, PCT, and TTI

Port of Rotterdam (RTM): APMT MV2, APMT, ECT Delta-North, ECT Delta-South, Euromax, and RWG

Port of Shanghai (Yangshan) (SGH): Shengdong, Guandong, and Shangdong

Port of Ningbo Port (NGB): BSCT, Daxie, Ganji, Meishan, NBCT, and Yuandong

4.2. Estimation Results

The numbers of berthing ships and the rate of offshore waiting ships during the period by terminal are indicated in Figure 9. The numbers of calling ships at terminals in the Ports of Los Angeles and Long Beach were small, while the numbers at the terminals in Rotterdam, Shanghai, and Ningbo were large and the rates of waiting ships were around 20 to 40 %. The berthing ships at the terminals in the Ports of Rotterdam and Ningbo included many feeder vessels, and the berth lengths of the terminals in the Port of Shanghai were relatively long.

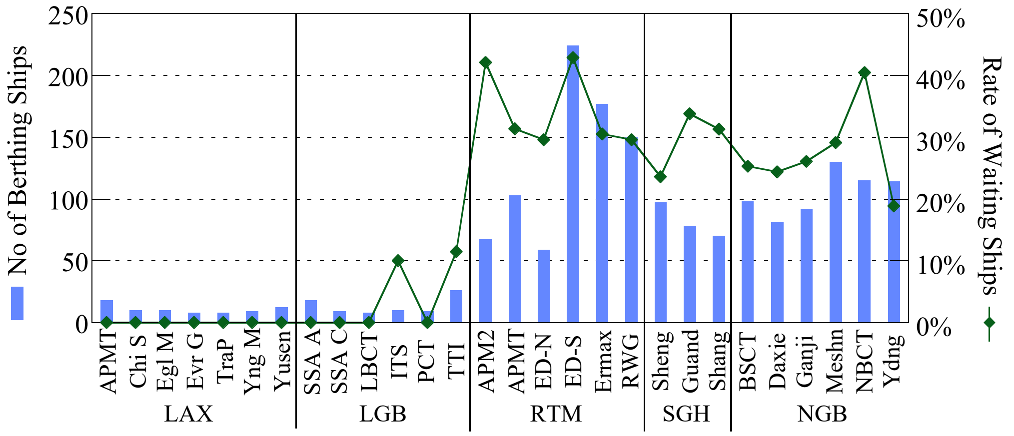

Figure 9 – Number of calling and waiting ships by terminal

The most important point for shippers is how long deliveries of their cargoes are behind schedule, since long delays induced by long offshore waiting can have a serious impact on the shipper's plans for production, sales, etc. Figure 10 shows the histogram of waiting time, and indicates that approximately 60 % of offshore waiting was finished within half a day. However, long waiting times were not rare, as 14 % of waiting ships waited longer than 1.0 day, and, these waiting times accumulated in ships, causing long service delays. Here, a ship waiting over one week at Pier A terminal of the Port of Long Beach was excluded because the berthing day of this ship was on schedule, and it was found that this waiting was simply for adjustment of the ship's schedule.

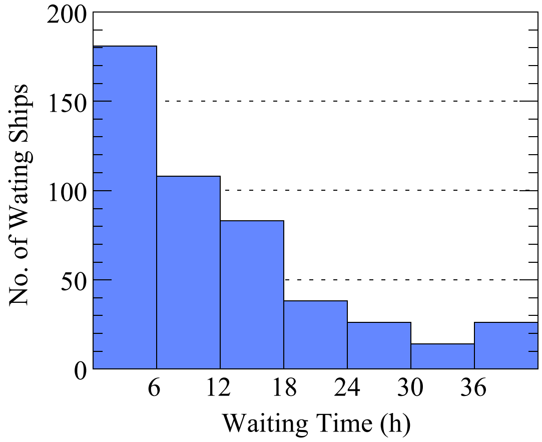

Figure 10 – Histogram of waiting times

The size of waiting ships is also an important factor because ship size is equivalent to the volume of waiting containers. The impact of waiting by a 20,000 TEU mega ship is extremely large compared with that of a 1,000 TEU feeder ship. That is, the important point here is how many and how long containers wait offshore from terminals. Thus, it is valid to measure the volume of offshore waiting by TEU multiplied by waiting time, namely "time-volume." The carrying container volume of each ship can be calculated by assuming the slot utilization rate is 60 %, considering the fact that the average global rate excluding interregional service was 62.9 % in 2019 according to Drewry (2020).

The waiting time-volume and average size (TEU capacity) of waiting ships by terminal are shown in Figure 11. Large differences were observed in both the waiting time-volume and ship size. The waiting ship size for terminals in the Port of Shanghai was very large, at approximately 10,000 TEU or over, while those of many terminals in the Ports of Rotterdam and Ningbo were less than 5,000 TEU. It was considered that waiting time-volume depended upon the characteristics of the terminals such as the berth length, degree of congestion, and share of delayed arrival ships.

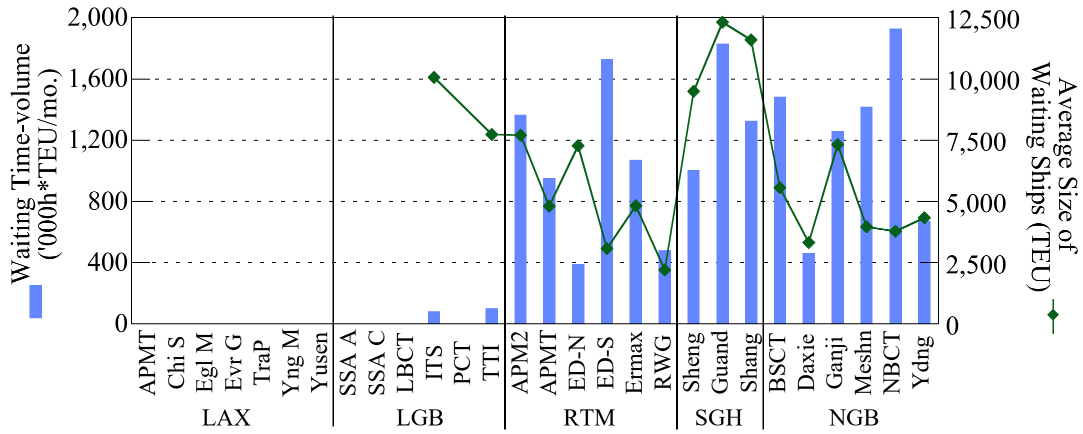

Figure 11 – Waiting time-volume and average size of waiting ships by terminal

4.4. Analysis of Terminal Characteristics

Since waiting time-volume is assumed to be linked to terminal congestion, the relationship between the berth occupancy ratio and waiting time-volume per berth length was calculated, as shown in Figure 12. The berth occupancy ratio is defined as the share of occupied space and time by berthing ships, including mooring lines, against total time and length. Basically, an increase in the berth occupancy ratio led to an increase in waiting time-volume, and in particular, waiting time-volume increased dramatically if the ratio exceeded about 30 %. However, it was also found that waiting time-volume was affected by the other factors because the correlation coefficient was not particularly high. For example, at the TTI terminal of the Port of Long Beach, the berth occupancy ratio and the waiting time-volume were 55 % and 66 hour*TEU/m respectively, while that same values at the Guandong Terminal of the Port of Shanghai were 33 % and 704 hour*TEU/m, both deviating greatly from the regression curve.

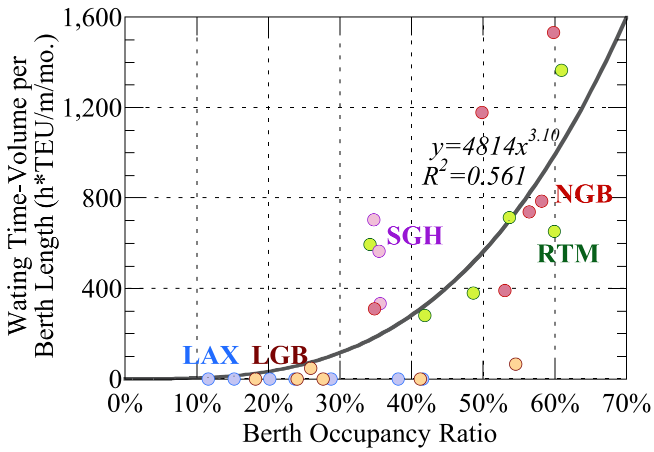

Figure 12 – Berth occupancy ratio vs. waiting time-volume per berth length

The characteristics of schedules possibly differ even at the same level of berth occupancy ratio. Table 6 shows examples of the number of berths and services for each terminal. Berths and services were categorized by mother vessel or feeder vessel. At the Yusen Terminal of the Port of Los Angeles and LBCT of the Port of Long Beach, the numbers of services per berth (B/A) were equal to or less than 1.0, which means that offshore waiting does not occur unless each ship catches up with the prior ship of the same service. The waiting time-volume at the Shandong Terminal of the Port of Shanghai was longer than at LBCT, although the berth occupancy ratio was smaller. At the Euromax Terminal of the Port of Rotterdam and NBCT of the Port of Ningbo, both the number of services and the waiting time-volume were much larger.

Table 6 – Number of berths and services of terminals

Port Terminal			LAX Yusen	LGB LBCT	RTM Euromax	SGH Shangdong	NGB NBCT
(A)	No. of Berths	Mother Vessel	3	2	2	6	2
		Feeder Vessel	0	0	2	0	2
(B)	No. of Services	Mother Vessel	2	2	6	15	10
		Feeder Vessel	1	0	25	0	7
B/A (Feeder=0.5)			0.83	1.00	6.17	2.50	4.50
Berth Occupancy Ratio			23.7%	41.2%	53.6%	35.4%	59.8%
Wating Time-Volume (h*TEU/m)			0	0	715	565	1,532

※Number of berths were actual use and not catalogue data.
※※Number of services was counted based on MDS data and excluded unknown data.

Table 6 implies that the number of services and ship size are linked to waiting time-volume. Figure 13 shows the relationship between the total TEU capacity of berthing ships and waiting time-volume per berth length. In spite of some scattering, a linear relationship can be seen in this figure. At terminals where many large ships berth, the intervals of services on their schedules are sometimes very short, and since large ships deployed in long-range service tend to be delayed, offshore waiting tended to occur easily.

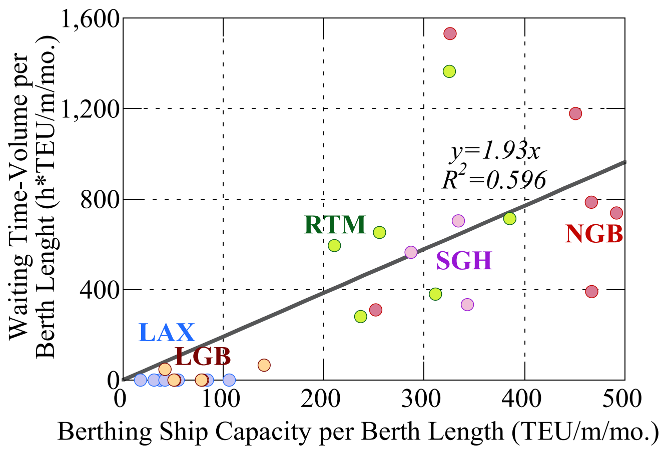

Figure 13 – Total TEU capacity of berthing ships vs. waiting time-volume

Offshore waiting does not occur if all ships arrive and depart on time, and conversely, offshore waiting increases as more ships are delayed and stay overtime. Figure 14 shows the actual arrival and staying time of ships in comparison with their schedules at each terminal. This comparison was restricted to only long-range services for which schedules could be obtained. From the left side of the figure, the shares of on-time arrivals were small at all terminals. At NBCT of the Port of Ningbo, more than half of arrivals were delayed over 24 hours, and many arrivals were delayed more than 48 hours. NBCT recorded the highest waiting time-volume in Figures 12 and 13, and this arrival delay condition was considered to be one of the main causes of the long waiting time-volume. On the right side of Figure 14, the majority of ship stays were under the scheduled times, and overtime stays of more than 24 hours were recorded only at

LBCT of the Port of Long Beach. Comparing the figures in Figure 14, the delays of arrival on the left were apparently large, indicating that offshore waiting was caused mainly by arrival delays, at least during the period observed here.

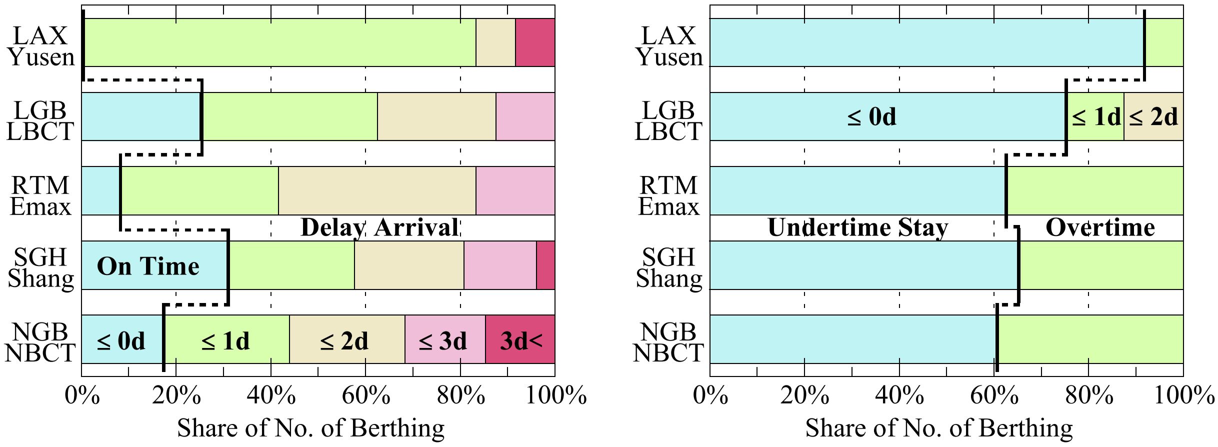

Figure 14 – Actual time of arrival (left) and staying (right) at each terminal

5. Discussion

5.1. Countermeasure against Delay for Shipping Companies

Delays in container services have a serious impact on global supply chains. Djankov *et al* (2006) indicated that each additional day that a product is delayed prior to being shipped reduces trade by at least 1 %. Akakura (2018) estimated that the decrease of 6.8 % in trade volume between North Europe and Japan due to the delay of direct container services in 2017, which averaged 2.1 days, resulted in GDP decreases of $180m to $260m in North Europe and $70m to $90m in Japan.

Shipping companies do not set schedules with a large time margin if shippers select services based on transport time on schedule and freight. Given this situation, a third index for selecting services namely, punctuality, is required in order to reduce service delays. At one time, shipping company websites provided service punctuality rates, but this information cannot be found recently. On the other hand, the Port of Vancouver publishes the share of arrivals within 8 hours of schedule by service as Gateway Vessel's On-Time Performance every month under the West Coast Supply Chain Visibility Program, and the Port of Rotterdam publishes the degree of delays of barge service by destination area every month as the Barge Performance Monitor. In addition, CMA-CGM provides the "SEAPRIORITY reach" service, which assures the arrival time at destinations in the U.S. for an additional charge, and this service has reportedly sold well. These trends suggest there must be many shippers that desire high punctuality service. Moreover, it is also possible that disclosing information on container service delays will be the driving force for reducing those delays.

5.2. Countermeasures against Waiting at Container Terminals

Container terminals can improve their operating profit by accepting more services at the same facilities, and offshore waiting does not occur if all ships arrive and depart on schedule. Under these circumstances, there is no large incentive for terminal operators to reduce offshore waiting time-volume by setting schedules with larger time margins. However, offshore waiting decreases the punctuality of services, and if this induces a decrease in the number of customers using the service, the container throughput of the terminal will also decrease. From this viewpoint, waiting time-volume can be one key performance indicator (KPI) for judging the soundness of terminal operation, and can also be considered when discussing the efficiency and necessity of investment in a terminal. Furthermore, for shippers that reserve services for spot cargoes, real-time data is very useful for avoiding services calling at terminals with long offshore waiting times. Figure 15 shows the number of anchoring container ships in the waiting sea areas of ports according to Marine Traffic. The numbers have fluctuated greatly over the long term, and after December 2020, a surge in container handling volume and lack of workers caused by COVID-19 lengthened the staying time of ships and increased the number of ships waiting offshore at the Ports of Los Angeles and Long Beach.

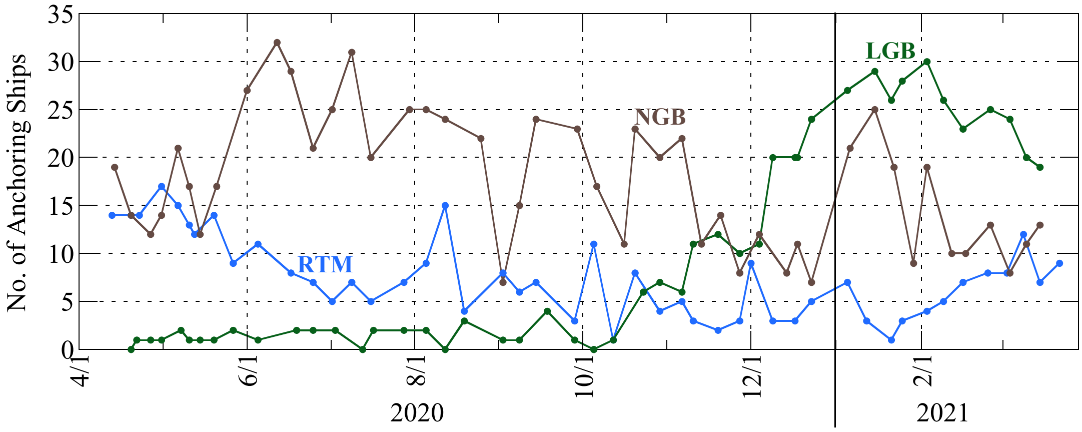

Figure 15 – Number of anchoring container ships offshore of ports

Data: Counted from Marine Traffic

The analysis results in the previous chapter revealed that terminals which had high berth occupancy ratios and berthed many large ships also tended to have long waiting time-volumes. In addition, offshore waiting possibly has a domino effect on the berthing terminal itself, as well as on other terminals, through ship delays. In responding to this condition, the offshore waiting time-volume proposed here is a useful index of terminal operation for improving the punctuality of container services. Figure 16 shows the plot of the degree of waiting time-volume on the coordinate surface of the berth occupancy ratio and total TEU capacities of berthing ships. From this result, although the waiting time-volume largely depends on actual arrival delay and overtime stay, medium waiting time-volumes (100 to 699 h*TEU/m) tended to occur at terminals with berth occupancy ratios of more than 30 % and berthing TEU capacities of more than 200 TEU/m, and large waiting time-volumes (over 700 h*TEU/m) tended to occur at terminals with occupancy ratios exceeding 50 % and more than 300 TEU/m. According to the argument here, for example, strengthening the handling capacity of a terminal by increasing the number of gantry cranes will lead to a shortening of staying time, namely, a decrease in the berth occupancy ratio, and extending the berth length will decrease both berthing TEU capacities per berth length and the berth occupancy ratio. However, in order to discuss measures for restraining offshore waiting time-volume, accumulation of a longer and wider range of data and deeper analysis will be needed, as this study was based only on the data for a one-month period at five ports. As shown in Figure 4, the main cause of delay is port/terminal congestion, but other factors such as low terminal/port productivity and bad weather also have some impacts. As to the latest situation, because of the spread of the COVID-19 infection, deterioration of the handling capacity of the Ports of Los Angeles and Long Beach (2020/21 winter) and prohibition of calling at the Ports of Dalian (December 2020) and Yantian (June 2021) led to numerous offshore waiting ships at those ports, which also had a domino effect on other ports. Since various factors are intricately related to waiting time-volume, more detailed modeling is required. From another point of view, optimization of berth allocation can also reduce offshore waiting time-volume, and many efforts have been made already in this field, as mentioned in Chapter 2.

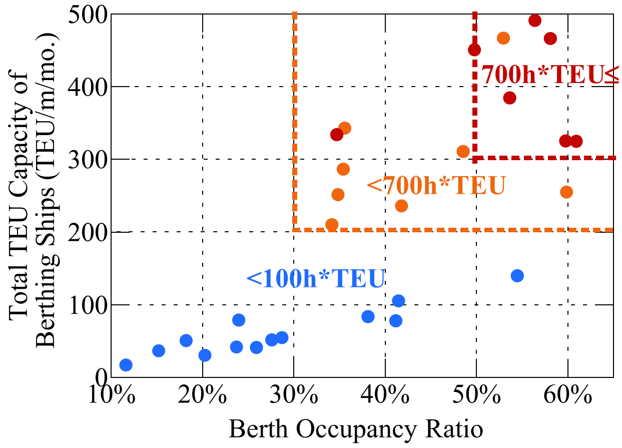

Figure 16 – Waiting time-volume vs. berth occupancy ratio and berthing TEU capacity

5.3. Consideration of Relationship of Shipping Companies and Terminals

Accompanying the rapid reorganization of shipping alliances, the services of the same alliance may now berth at different terminals in the same port. Table 7 shows the berthing terminals of each alliance at the five ports studied here. Although there is a one-to-one correspondence between alliances and terminals at the Port of Shanghai, there are several terminals that are owned by shipping companies in the same alliances at the Port of Los Angeles. While a dedicated terminal has the merit of greater flexibility when a ship's schedule is disrupted, it sometimes does not have a large capacity as a margin against concentrated calls, and drayage is necessary if containers are transshipped between ships berthing at different terminals. In Figure 6 and Figure 12, differences were seen in the delay times and offshore waiting time-volumes of terminals at the same ports. Based on this condition, a movement to merge container terminals has been seen. In January 2019, four terminals at the Port of Hong Kong established the Hong Kong Sea Port Alliance and integrated their operation. The Singapore Port Authority is now constructing a new mega container terminal called Tuas, and with the completion of that terminal, five existing terminals will eventually be merged at Tuas to increase operational efficiency by eliminating inter-terminal haulage. At the Port of Rotterdam, the Container Exchange Route project is in progress and will connect five container terminals in the Maasvlakte area by a dedicated road network utilizing autonomous vehicles. Decreasing both offshore waiting time-volume at terminals and delays in service are expected as a result of the enhanced operational efficiency provided by this kind of consolidation of terminals.

Table 7 – Berthing terminals of each alliance

Alliance	LAX	LGB	RTM	SGH	NGB
2M	APMT	TTI	APMT APMT MV2 ECT Delta-N	Guandong	Ganji Meishan
The Alliance	China Ship. Tra Pac Yang Ming Yusen	ITS	ECT Delta-S RWG	Shangdong	BSCT Daxie Meishan NBCT
Ocean Alliance	China Ship. Eagle Marine Ever Green	LBCT PCT	ECT Delta-S Euromax RWG	Shengdong	Daxie Meishan NBCT Yuandong

6. Conclusion

One of the major causes of service delays and offshore waiting at terminals is considered to be the concentration of calling at specific ports and terminals induced by consolidation of services accompanying the reorganization of shipping alliances. Offshore waiting occurs when a ship arrives late or overstays at a congested terminal, and this not only lengthens the delay of the ship concerned, but also causes offshore waiting of the following ships at the terminal and the spread of service delays to other terminals and ships. For cutting-edge global supply chains, it is essential to break this vicious circle.

This study quantified the delays on container trunk lines, analyzed the causes, and estimated the offshore waiting time of ships calling at congested terminals. The delays of container ships deployed on trunk lines were calculated by comparing the actual arrival/departure times in the ship movement data and the scheduled times at calling ports. The offshore waiting times of ships for calling at container terminals were estimated by calculating the total times and the hourly ship speeds between entering port and the berthing terminal, as well as the detected anchoring signals, utilizing AIS data.

The results of this study revealed that the punctuality rate of trunk lines in 2018 was below 70 %, and approximately 80 % of delays occurred at ports in China, Europe, and North America. At these ports, the delays of services at each terminal differed significantly even in the same port. The offshore waiting time-volume index, which was newly proposed in this study, displayed a relationship to the berth occupancy ratio and total TEU capacity of berthing ships, and also depended on actual delays of arrival and overtime stays. Methods for decreasing delays of container services and waiting time-volume at terminals were also discussed from the viewpoints of improving terminal efficiency and container service punctuality.

The contribution of this study to the literature is as follows: (1) This study quantified the delay of East-West container services in broad terms and analyzed the causes of delays, and (2) proposed an estimation method for the offshore waiting time of each ship at container terminals, making it possible to discuss the relationship between waiting time-volume and the situations and characteristics of terminals such as the degree of congestion, the total TEU capacity of ships, delays of ship arrival, and over stays of berthing ships.

As mentioned in section 5, the scope of this study when calculating the offshore waiting time-volume was limited in both time and the number of ports. The authors plan to address this issue in future work by not only increasing the analysis targets, but also by modeling the occurrence of offshore waiting at terminals, with the aim of improving the punctuality of global container services and operational efficiency of container terminals.

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